

# **Determination of Mesoscale Predictability Limits with Respect to Uncertainty in the Larger-Scale Environment**

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## **LONG-TERM GOALS**

Our long-term goal is to determine the limits of predictability inherent in atmospheric forecasts due to uncertainty in their initial conditions. These uncertainties are a consequence of inaccuracies of observational data and the algorithms that produce 3-dimensional analysis. Even if a model can simulate atmospheric behavior perfectly, since atmospheric flows exhibit instabilities leading to chaos, any errors in a forecast's initial condition will tend to grow, until information content of the forecast is negligible. The result is a limit to predictability.

This predictability limit has been known for some time (Lorenz, 1963), although it continues to be ignored by some who make very optimistic claims (e.g., the U. S. Weather Research Plan goals of useful 10-day weather forecasts and 48-hour quantitative precipitation forecasts). Its character, especially regarding how various types of errors influence the predictive skill of various fields on various scales, has only been superficially explored to date (Lorenz, 1969; Errico et al., 1995). Since characterization of this limit has crucial implications regarding forecast reliability and possible observation system impacts, its determination is critical (Tribbia and Baumhefner, 1988).

## **OBJECTIVES**

Our objective in this particular study is to determine the predictability limits of weather forecasts caused by inaccuracies in their initial conditions and to characterize the processes of forecast error growth. In particular, we will determine these limits and characterize the processes as functions of

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horizontal scale. Results will depend on the fields being forecast: Although the predictability limit for forecasting 50 kPa geopotential height anomalies may be as long as 8 days with present observation and data assimilation systems, it is likely considerably shorter for forecasts of the small-scale processes that generate clouds or precipitation. Yet for many purposes, it is these more poorly determined fields that are of paramount interest.

Both the energy and variances of fields are much greater at synoptic and planetary scales than at mesoscales. Initial conditions for forecast models therefore also tend to have errors that dominate at these larger scales. It has been argued that mesoscale errors grow more rapidly or, alternately, that they are more predictable, but these have been on heuristic grounds, using either simple models (Lorenz, 1969) or flawed experimental designs (e.g., Anthes et al., 1985, as revealed by Errico and Baumhefner, 1987). One of our goals will be to perform careful experiments to characterize the interaction of mesoscale and synoptic-scale errors using the most realistic and highest resolution global model that we can presently afford to use.

## **APPROACH**

We assume a perfect model. For this reason, the model must be carefully verified with regard to its abilities to both forecast weather and simulate climate. It must be neither overly damped nor too energetic, otherwise perturbations will not behave consistently with respect to forecast errors. Tests of version 3 of NCAR's Community Climate Model (Hack et al., 1993) reveal it is such a suitable model.

Initial condition perturbations are created by randomly sampling from an error probability distribution that has some assumed characteristics of analysis errors. We can only base this on "assumed" characteristics because very limited effort has been applied to revealing the true character of such errors. Estimated analysis errors reported by Daley and Mayer (1986) and from examination of differences between analyses produced at NCEP and ECMWF are used as guidance, along with knowledge about the current observation system and intuition regarding the behavior of data assimilation systems.

For selected forecast periods, ensembles of randomly perturbed forecasts are created. They are then examined using standard forecast verification tools as well as statistical tests on all the pairs of forecast differences. Scales are distinguished using spherical harmonics as basis functions. Other techniques will be applied as well, as required.

## **WORK COMPLETED**

During the past year we have worked on 4 aspects of our problem (each described following). All this work is now at the stage where outlines have been developed in preparation for writing 4 manuscripts describing each aspect separately. Work on these aspects will continue as the writing proceeds.

We have begun comparison of the latest NCEP and ECMWF re-analysis for a five-year period for the purpose of characterizing the statistics of analysis error. So far, only corresponding 6-hourly analyses for a period of 5 days were examined in detail. Our attention was focused on geopotential height fields, since currently the precipitation fields provided with these analyses are strictly model-forecast results, independent of any actual observations of precipitation. This work is in preparation for a more extensive statistical analysis we plan to begin this fall after new software capabilities are developed.

Characteristics of the growth of perturbations were compared for T42, T63, T106, and T170 resolutions of the CCM3. Attention was focused on the 50kPa geopotential height field. Perturbations were examined as functions of geographic location and total, spherical harmonic wave number. Also, unperturbed forecasts were begun for the four resolutions with topography removed and using identical initial conditions at any of the commonly resolved scales. The purpose of this experiment was to explore the effect of unresolved scales on the resolved ones.

Ensemble forecasts produced at NCAR, NCEP, and ECMWF have been compared. The behaviors of individual realizations of perturbations, their horizontal spectra, and the geographical distribution of their ensemble variances have been examined. This attention has also focused on the 50kPa geopotential height field, because it is one of the few fields provided by the other centers.

In recognition of the importance of predictability error growth in limiting forecasts and of the lack of knowledge of the nature of this growth within the general meteorological community, we have begun preparation of an article for the Bulletin of the American Meteorological Society characterizing what has been learned since predictability limits were first hypothesized. This article will include descriptions of how fast errors grow (doubling of rms global 50kPa geopotential height perturbations every 1.5 days) and on what scales the errors grow (planetary and large synoptic scales, peaking at total wave number 10).

## RESULTS

Preliminary comparison of the NCEP and ECMWF re-analysis reveals rather large differences in oceanic locations, where current observations are of poorer quality than over Northern Hemisphere land areas. At 50kPa, average oceanic height differences are approximately 50m, corresponding to 2.5C mean temperature differences in the lower half of the atmosphere. These differences actually peak in the scales of planetary waves. The largest differences are observed in structures where the 6-hour height changes are greatest. There is significant temporal continuity in the analysis differences, indicating the importance of the differing background fields used in each analysis system.

Statistics of the growth of ensembles of perturbations in the T170 CCM3 are nearly identical to those in the T106 version. This includes variances of perturbations as functions of geographic location, total wave number, and time. The mean growth rate is the same as that reported by Simmons et al. (1995) for the ECMWF model. This growth rate is also consistent with the average rate of growth of actual forecast errors, in that it is an underestimate of the latter growth because we have neglected consideration of model error. The variance of the ensemble perturbation fields is also geographically correlated with the locations of forecast error.

Although the CCM3 ensembles we have produced begin from perturbations whose structures are very different than those used for the ECMWF ensembles, by day 2, the variances of the subsequent ensemble forecasts are very similar. This similarity regards geographic locations, horizontal scales, and magnitudes. All are associated with baroclinically growing structures. Some differences between the ECMWF and CCM3 results do exist, but it is as yet unclear whether these are due to under-sampling in either ensemble or due to the dynamic constraint implied in the ECMWF initial perturbations. The NCEP ensembles do not appear consistent with the behavior of forecast error growth in the NCEP system, nor with what we have ascertained about analysis differences, nor with either the NCAR or ECMWF ensembles.

When T63, T106, and T170 forecasts were begun from identical initial conditions at their common scales, differences at the smallest resolved scales in the lower resolution experiments were quickly seen, presumably due to different behaviors of model physics. Once the planetary scales were perturbed by these smaller scale perturbations, however, the differences at the smallest scales did not grow enough to influence the subsequent, more dominant growth of differences in the planetary scales.

The impact of small-scale perturbations on the planetary scale was therefore negligible, aside from initiating perturbations on the larger synoptic planetary scale.

## **IMPACTS/APPLICATIONS**

NCAR's CCM3 appears to be suitable as a forecast model, with comparable skill to ECMWF and NCEP models at the same resolutions when measured using rms 50kPa geopotential height errors. At T106 resolution, the character of perturbation growth is similar to the T170 result, so that T106 or even T63 simulations appear sufficient for examining our problem.

## **RELATED PROJECTS**

Work on various aspects of singular vectors is being performed in collaboration with Kevin Raeder at NCAR, Martin Ehrendorfer at the University of Vienna, Austria, and Carolyn Reynolds and Ron Gelaro at NRL, Monterey.

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## **PUBLICATIONS**

Four manuscripts are in preparation.